The effectiveness of mechanical exhaust ventilation in dwellings

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ABSTRACT

Ventilation systems play an important role in providing a good indoor air quality in dwellings. Mechanical exhaust ventilation systems implement natural vents to supply outdoor air to the dwelling. Natural driving forces, i.e. wind and thermal draught, influence the flow rates through these supply vents. Therefore, the flow rates depend on the weather conditions and vary in time. This study considers the influence of the wind and thermal draught on the operation of a mechanical exhaust ventilation system in a reference dwelling. Furthermore, the influence of the sizing of the natural vents and the airtightness of the dwelling envelope are taken into account. This paper covers a simulation study investigating the effects of wind, thermal draught, the sizing of the natural vents and the building airtightness on the flow rates in the dwelling by using multizone airflow and contaminant transport calculation software (Contam). Wind and thermal draught create a spread on the supply flow rates. Therefore, the flow rates through the vents are not always as designed. The airtightness also influences the flow rate through the vents. Both effects (wind/thermal draught and airtightness) depend largely on the sizing of the natural vents.

KEYWORDS

Mechanical exhaust ventilation, flow rates, IAQ, Airtightness

1 INTRODUCTION

Mechanical exhaust ventilation systems (called systems C in this paper) supply outdoor air to the dwelling by using natural supply vents and extract the indoor air from the dwelling with a mechanical ventilator(AIVC, 1996). The natural supply vents are openings in the building envelope designed for a specific airflow rate at a specific pressure difference. Currently, the Belgian standard NBN D50-001 (1991)defines the flow rate of a fully opened natural supply vent at a pressure difference of 2 Pa. Supply vents can also be self-regulating to prevent overventilation at high wind pressures. Self-regulating vents respond to the wind pressure and reduce the airflow through the supply vents by closing a valve when the wind pressure exceeds a predefined pressure, e.g. the design pressure. In Belgium, these self-regulating vents are classified into 5 categories, i.e. P0 (non-self-regulating) to P4, each with specific characteristics for the pressure profile of the closing valve (NBN EN 13141-1: 2004).

The actual pressure differences over the supply vents fluctuate in time due to natural driving forces, i.e. wind and thermal draught. Therefore, the actual supply flow rates through the vents vary in time depending on the weather conditions.

However, the mechanical extraction ensures a specific extraction rate in the dwelling and as a result the same airflow rate must enter the dwelling. The air flow can enter the dwelling through the natural supply vents but also through the cracks in the building envelope. Due to the natural forces and the airtightness of the dwelling, the flow rates through the vents and the flow paths through the dwelling are not always as designed, depending on the sizing of the vents.

This paper discussesthe influence of the wind and thermal draught on the airflow rate through the natural vents by taking the sizing of the natural vents and the airtightness of the dwelling envelope into account. This influence is investigated based on multi-zone flow rate simulations in CONTAM

2 METHODS

The simulation study uses multi-zone airflow and contaminant transport calculation software CONTAM to determine the airflow through the natural vents in two reference dwellings.

The first reference dwelling used in this study represents a one-storey detached, three-bedroom house with a total living area of 117 m² (Figure 1).

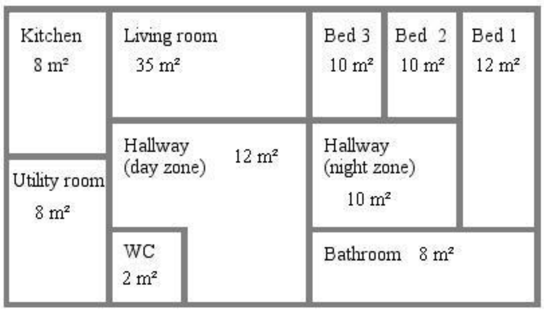

Figure 1: the one-storey dwelling is one of the two reference dwellings used in this study

The second dwelling is a two-storey detached, three-bedroom house with the same total living area as the one-storey reference dwelling. The day zone (living room, kitchen, utility room, WC, entranceway) is located downstairs and the night zone (bedrooms, bathroom, hallway)upstairs (Figure 2).

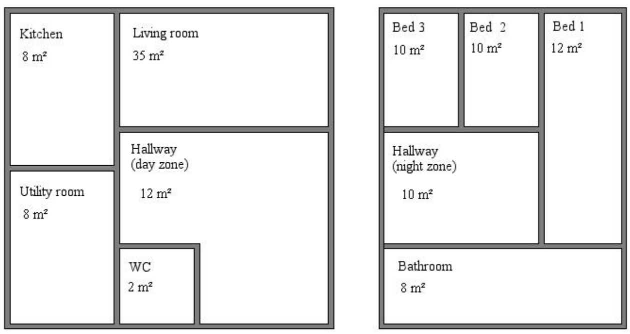

Figure 2: the two-storey dwelling, with the day zone downstairs and the night zone upstairs, is the second reference dwelling used in this study.

The design airflow rate for each room in these dwellings is calculated based on 7 l/s.person (Class II NBN EN 15251). The supply and extraction airflows are balanced.

Both dwellings are equipped with a system C. This systems implements natural supply vents in the living room and bedrooms. The sizing of these vents varies throughout the study:

	Living room	Bedroom 1	Bedroom 2/3
1	100 m³/h @ 2 Pa	50 m³/h @ 2 Pa	25 m³/h @ 2 Pa
2	100 m³/h @ 10 Pa	50 m³/h @ 10 Pa	25 m³/h @ 10 Pa
3	100 m³/h @ 20 Pa	50 m³/h @ 20 Pa	25 m³/h @ 20 Pa

The natural supply vents used in this study are both self-regulating (class P3), namely the supply vents @ 2 Pa and non-self-regulating (class P0), namely the supply vents @ 10 Pa and @ 20 Pa. The design flow rates of self-regulating vents of class P3 occur at 2Pa while by closing the valve the flow rate at 4.5 Pa is maximum 1.5 times the flow rate at 2 Pa. The non-self-regulating vents of class P0 don't include a closing valve.

The airtightness, defined as the airflow through the dwelling envelope per m² at a pressure difference of 50 Pa (air permeability q_{50}), also varies throughout the study(Belgian Building Research Institute (BBRI), 2015):

Airtightness 1	+- airtight
Airtightness 2	1 m³/h.m²
Airtightness 3	3 m³/h.m²
Airtightness 4	6 m³/h.m²

To transfer the air from one room to another, air flows through internal openings. Four different internal transferscenarios are implemented:

Internal transfer 1	Closed doors with transfer grilles and closed staircase
Internal transfer 2	Closed doors with transfer grilles and open staircase
Internal transfer 3	Open doors and closed staircase
Internal transfer4	Open doors and open staircase

The internal transfer openings are simulated as follows:
Transfer openings in closed doors with flow coefficients (C) accordingly to the design flow rate of the transfer opening, e.g. $C = 0.00593037 kg/s/Pa^n$ for a transfer opening of 25 m³/h @ 2Pa and a flow exponent n = 0.5. Open doors with flow coefficients of $C = 1 m^3/s/Pa^n$ and a flow exponent n = 0.5.

The hourly Test Reference Year Uccle is used to determine the outdoor conditions. This file contains, among other parameters, the wind speed, the wind direction and the outdoor temperature of an entire 'reference' year in Uccle. The indoor temperature is 18°C. The simulation reporting time is set to each minute, corresponding to the simulation time step.

The airtightness is simulated by 2 cracks in the outer wall of each room. The first crack is located at ¼ of the height of the wall and the second at ¾. The in-/exfiltration rate through each crack is determined according to the surface area that each cracks represents (uniform airtightness/air permeability). The in/exfiltration rate through the roof is evenly divided over the cracks in the walls.

3 RESULTS AND DISCUSSION

The simulation results show the influence of wind, thermal draught, the building airtightness and the sizing of the natural supply vents on the airflow rate through the natural vents or in other words on the effectiveness of a system C.

Following three schemes are investigated:

1. No wind, no thermal draught in an airtight and a leaky building
2. Influence of wind and thermal draught in an airtight building
3. Influence of wind and thermal draught in a leaky building

To clearly show the simulation conditions of each scheme, a table summarizes these conditions for each presented result.

3.1 No wind and no thermal draught in an airtight and a leaky building

The simulations investigate the influence of the sizing of the natural supply vents on the airflow rate in both an airtight and a leaky dwelling without the influence of the weather conditions, i.e. no wind and no thermal draught (Figure 3). Thereby, the flow rate through the vents only depends on the mechanical extraction rate of the ventilation system.

Simulation conditions	
Dwelling	Reference dwelling 1 (one-storey)
Airtightness	Airtight
	Leaky: 1 m³/h.m², 3 m³/h.m², 6 m³/h.m²
Outdoor conditions	Steady state:no wind, no thermal draught
Size natural supply vent	P3@ 2 Pa, P0@ 10 Pa, P0@ 20 Pa
Internal resistance	Closed doors

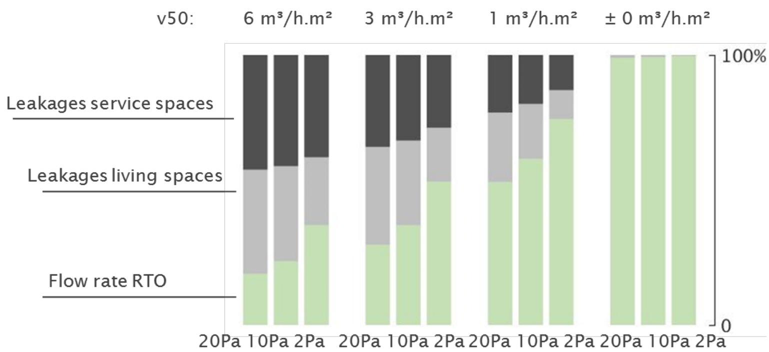

Figure 3: This figure represents the percentages of the total supply flow rate through the natural vents (RTO) (light green), through the leakages in the building envelope in the living spaces (light grey) and through the leakages in the service spaces (dark grey) for different levels of airtightness (increasing airtightness from left to right) and different sizes of natural vents (increasing sizes from left to right).

In an airtight dwelling and given no wind and no thermal draught, the sizing of the supply vents doesn't influence the flow rate of the building. Approximately 100% of the flow rates enters through the vents independent of the size. In a leaky dwelling, the sizing of the supply vents influences the flow rate through the supply vents. In a leaky dwelling, air will enter through the vents but also through the leakages in the building envelope. The lower the airtightness of the dwelling, the more air will enter through the leakages. Furthermore, a lower airtightness leads to a lower total supply flow rate (vents + leakages) in the living spaces but additional supply flow rate in the service spaces. Smaller vents (10 Pa and 20 Pa) enhance both these effects (Figure 3).

3.2 Influence of wind and thermal draught in airtight building

The simulations investigate the influence of wind and thermal draught, independently (results not shown), and simultaneouslyon the flow rate of an airtight dwelling (Figure 4). Furthermore, the influence of the internal transfer openings (Figure 4 and Figure 5) and the sizing of the supply vents is taken into consideration (Figure 6). The flow rate in the dwelling no longer depends solely on the mechanical extraction of ventilation system but also on the outdoor weather conditions.

Simulation conditions	
Dwelling	Reference dwelling 2 (two-storey)
Airtightness	Airtight
Outdoor conditions	Steady state: fixed values for wind speed and direction (results not shown)
	Steady state: fixed values for thermal draught (results not shown)
	Transient: TRY Uccle
Size natural supply vent	P3@ 2 Pa (Figure 4 and Figure 5)
	P0@ 10 Pa (Figure 6)
Internal resistance	Closed doors + closed staircase (Figure 4)
	Closed doors + open staircase (results not shown)
	Open doors + closed staircase (results not shown)
	Open doors + open staircase (Figure 5 and Figure 6)

In an airtight dwelling and due to wind only, the airflow rates through the vents are not as designed (results not shown). The flow rates through the vents in the living spaces at the windward side are higher, while the flow rates in through the vents in the living spaces at the leeward are lower. Leading in some cases, even to reverse airflow rates, i.e. extraction. Due to only thermal draught (results not shown), the flow rates through the vents in the living room on the ground floor are higher, while the flow rates in bedrooms on the first floor are lower for outdoor temperatures <the indoor temperature (18°C). The effect increases with decreasing outdoor temperature. Therefore, the wind and thermal draught are responsible for a flow rate variability.

The results of the simulations with the transient TRY Uccle conditions are presented in a frequency distribution graph, showing the percentage of time when a certain airflow rate occurs.

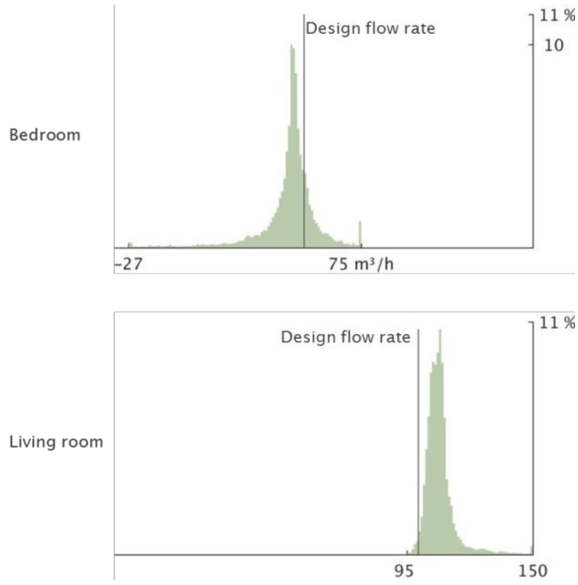

Figure 4: This figure represent the frequency distribution graph of the airflow rates (m³/h) through the natural self-regulating vents of 2 Pa in both the living room on the ground floor (bottom) and a bedroom at the first floor (top) of an airtight building with closed doors and a closed staircase (high internal resistance). The design flow rates for the living room (100 m³/h) and bedroom (50 m³/h) are indicated by the vertical line.

In the airtight dwelling, the airflow rates in the living room on the ground floor and in the bedroom at the first floor vary in time and are not as designed. The flow rate in the living room is mostly higher than designed (Figure 4: bottom) and in the bedroom lower than designed. In the bedroom even reversed flow, i.e extraction, occurs sometimes (Figure 4: top).

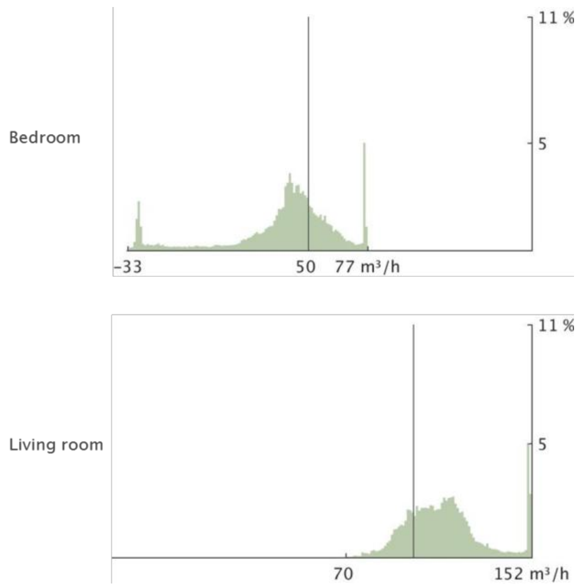

Figure 5: This figure represent the frequency distribution graph of the airflow rates (m³/h) through the natural self-regulating vents of 2 Pa in both the living room on the ground floor (bottom) and a bedroom at the first floor (top) of an airtight building with open doors and an open staircase (low internal resistance). The design flow rates for the living room (100 m³/h) and bedroom (50 m³/h) are indicated by the vertical line.

In an airtight building the negative effect of thermal draught is higher with lower internal resistance, i.e. bigger openings(Figure 4 and Figure 5). Therefore, the open doors and open staircase lead to the least controlled airflow rates, i.e. widest distribution and thus the least favourable scenario. The following simulations all implement this scenario as it is the most negative. A narrower distribution occurs at high internal resistance, meaning closed doors and a closed staircase with transfer openings (internal transfer scenario 1) lead to more controlled airflow rates closer to the design flow rate.

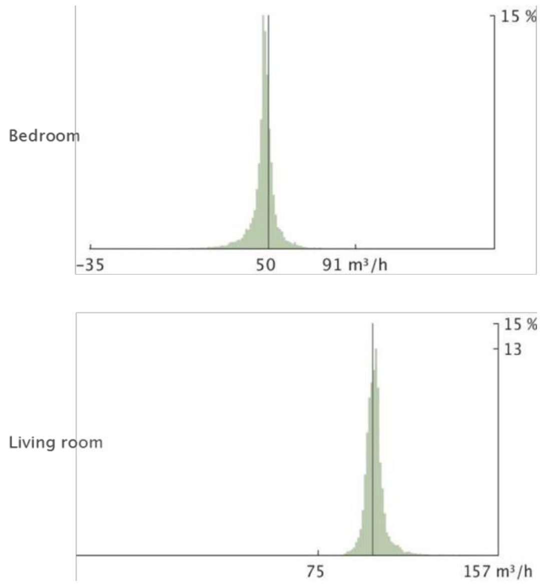

Figure 6: This figure represent the frequency distribution graph of the airflow rates (m³/h) through the natural vents of 10 Pa in both the living room on the ground floor (bottom) and a bedroom at the first floor (top) of an airtight building with open doors and an open staircase (low internal resistance). The design flow rates for the living room (100 m³/h) and bedroom (50 m³/h) are indicated by the vertical line.

In an airtight dwelling, the smaller supply vents, i.e. 10 Pa, lead to more controlled airflow rates compared to the larger self-regulating vents of 2 Pa (Figure 5 and Figure 6). The smaller vents reduce both the variable effect of the wind and the effect of thermal draught on the reduction of the flow rate in the bedrooms

3.3 Influence of wind and thermal draught in a leaky building

The simulations investigate the influence of wind and thermal draught (simultaneously) on the flow rate in a leaky dwelling. Airflow will enter the dwelling through the designated supply vents but also through the leakages in the building envelope. Furthermore, the influence of the sizing of the supply vents is taken into consideration. The airflow rates through the vents and the leakages not only depend on the mechanical ventilation and weather conditions, but also on the level of airtightness of the building envelope.

Simulation conditions	
Dwelling	Reference dwelling 2 (two-storey)
Airtightness	Leaky: 3 m³/h.m²
Outdoor conditions	Transient: TRY Uccle
Size natural supply vent	P3@ 2 Pa (Figure 7)
	P0@ 10 Pa (Figure 8)
Internal resistance	Open doors + open staircase

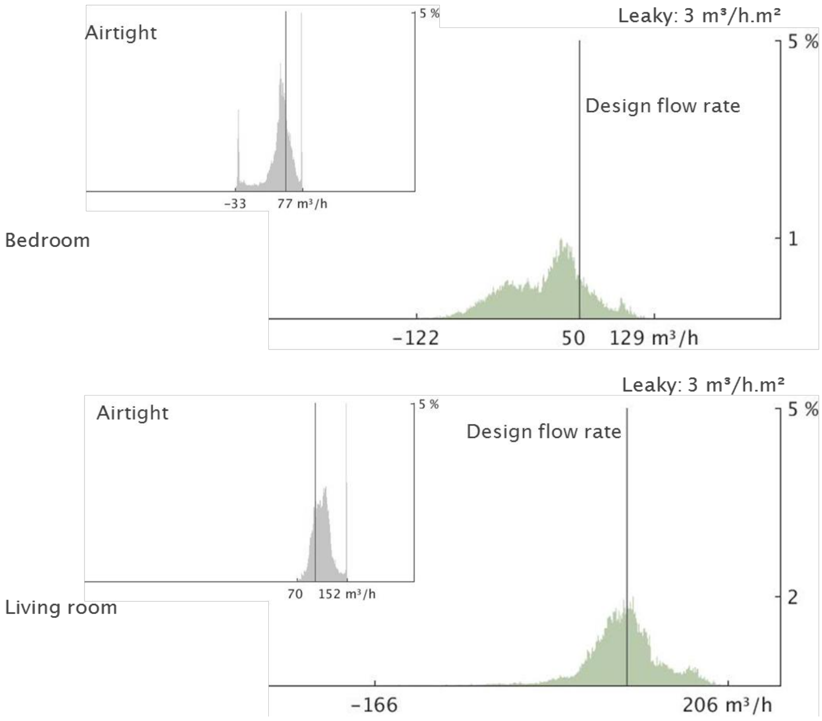

Figure 7: This figure represent the frequency distribution graph of the airflow rates (m³/h) through the natural vents of 2 Pa in both the living room on the ground floor (bottom) and a bedroom at the first floor (top) of a leaky building (q_{50} = 3 m³/h.m²) (right) with open doors and an open staircase. The design flow rates for the living room (100 m³/h) and bedroom (50 m³/h) are indicated by the vertical line. As a reference the results of the airtight building (i.e. results Figure 5) are repeated (smaller graphs on the left).

In the leaky dwelling, as in the airtight dwelling, the airflow rate through the natural supply vents in the living room (ground floor) and in the bedroom (first floor) varies in time and is not as designed (Figure 7). However, the influence of the wind and thermal draught is even bigger in the leaky building as the flow rates are even more variable. Reversed flow, i.e extraction, occurs sometimes both in the bedroom and living room.

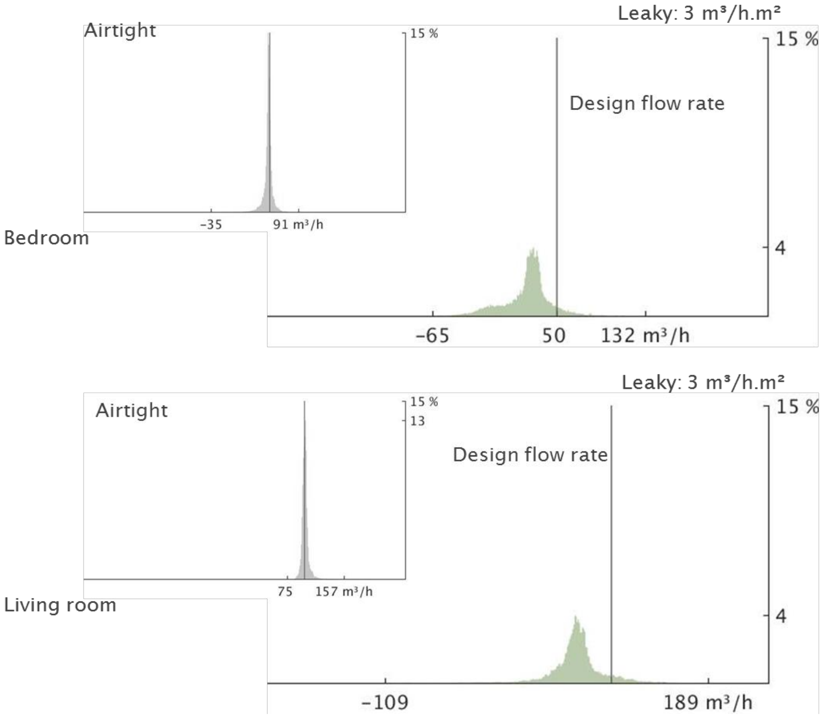

Figure 8: This figure represent the frequency distribution graph of the airflow rates (m³/h) through the natural vents of 10 Pa in both the living room on the ground floor (bottom) and a bedroom at the first floor (top) of a leaky building (q_{50} = 3 m³/h.m²) (right) with open doors and an open staircase. The design flow rates for the living room (100 m³/h) and bedroom (50 m³/h) are indicated by the vertical line. As a reference the results of the airtight building (i.e. resultsFigure 6) are repeated (smaller graphs on the left).

The smaller natural supply vents of 10 Pa aren't as favourable as in the airtight building. The airflow rates through the supply vents in the leaky building (q_{50} = 3 m³/h.m²) are lower and more variable (wider spread) compared to the vents in the airtight building (Figure 8). However, compared to the larger self-regulating supply vents of 2 Pa in the same leaky dwelling, the flow rate is less variable (narrower spread) but nearly always lower than the design flow rate (Figure 7 and Figure 8).

4 CONCLUSIONS

Without the influence of the outdoor conditions, i.e. no wind and no thermal draught, the sizing of the natural supply vents doesn't influence the airflow rate through the supply vents in an airtight building. However, the sizing does influence the airflow rate through the supply vents in a leaky building. The flow rate through the vents reduces and the flow rate through the leakages increases with decreasing airtightness. This effect increases with smaller supply vents.

In an airtight dwelling, wind and thermal draught influence the flow rate through the natural supply vents. The flow rates are variable in time and not as designed. Wind is responsible for higher flow rates in the rooms at the windward side and lower or even negative flow rates at the leeward side. Thermal draught is responsible for higher supply flow rates downstairs (living room) and lower supply flow rates upstairs (bedrooms)

In an airtight building, the internal transfer and sizing of the natural supply openings influence the flow rate through the supply vents. Bigger transfer openings, e.g. open doors, enhance the negative effect of thermal draught, while smaller natural supply openings, e.g. P0@10Pa, lead to less variable and more controlled flow rates, closer to the desired design flow rate.

In a leaky dwelling, wind and thermal draught also influence the flow rate through the natural supply vents with even bigger negative effects than in an airtight building. Smaller natural supply vents are not as favourable in leaky buildings as in airtight buildings. Lower flow rates occurs compared to the airtight dwelling. However, compared to the larger supply vents in the same leaky dwelling, the flow rate is less variable but nearly always lower (than the design flow rate).

5 ACKNOWLEDGEMENTS

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